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SEWAGE STABILIZATION PONDS IN THE DAKOTAS: AN EVALUATION OF THE USE OF STABILIZATION PONDS AS A METHOD OF SEWAGE DISPOSAL IN COLD CLIMATES. VOLUME I

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1967

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SEWAGE STABILIZATION PONDS IN THE DAKOTAS

VOLUME I

A JOINT REPORT WITH THE

NORTH AND SOUTH DAKOTA DEPARTMENTS OF HEALTH

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PUBLIC HEALTH SERVICE

1957

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SEWAGE STABILIZATION PONDS IN THE DAKOTAS

An evaluation of the use of stabilization ponds as a method of sewage disposal in cold climates

Volume I

A Joint Report
with

North Dakota
Department of Health
Bismarck, North Dakota

South Dakota
Department of Health
Pierre, South Dakota

Details of illustrations in
this document may be better
studied on microfiche.

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Sanitary Engineering Services

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio
1957

I

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Chapter I

SUMMARY OF FINDINGS AND RECOMMENDATIONS

SUMMARY

A field investigation of sewage stabilization ponds in the Dakotas was conducted during the winter, spring, summer, and autumn of 1955, and winter-spring transition period of 1956. Physical, chemical and biological phenomena were observed and correlated with structural design, operational practice and climatological features.

The process of waste stabilization in an open body of water involves a complex biological-chemical relationship between algae and bacteria. Algal activity is almost negligible under snow-covered ice; stabilization that is accomplished during the winter months in the Dakotas is primarily a result of physical forces and anaerobic bacterial activity.

Treatment obtained during both open water and ice-cover is very good. Reduction in concentration of B. O. D. ranged from 74 to 98 per cent during the open water seasons and from 70 to 96 per cent under ice. One installation had an average depth of only 14 inches,

and when frozen to a depth of 11 inches, had a concentrated liquid depth of three inches on the bottom; this concentration resulted in somewhat less reduction of B. O. D., 44 per cent.

Factors which affect the treatment process in a stabilization pond include the strength and type of sewage, loading per unit of surface area, sunlight, temperature, wind, depth, inlet and outlet structures and their location, and soil characteristics. In addition to consideration of these factors, selection of a site for a stabilization pond must be based also on economic factors such as land cost and gravity flow versus pumping for alternate sites of different elevation, as well as soil characteristics, and wind direction with respect to the community and outlying residences.

The use of stabilization ponds as a method of sewage treatment has become increasingly popular in the Dakotas. From 1949, when the first installation was constructed, to 1956, the total number has increased to more than 70 in North and South Dakota. The moderate per capita cost of construction and operation of stabilization ponds in small communities, as compared with more conventional treatment processes, is a primary reason for this popularity. Many communities have installed complete sewerage systems with a stabilization

pond, whereas the cost of a similar system with a conventional treatment plant had been prohibitive. An approximate range of per capita costs for Dakota ponds, not including the cost of lift stations, is from $4.40 to $37.94.

Public health considerations in the use of stabilization ponds must necessarily go beyond the extent of bacterial removal normally applied to a conventional treatment plant as a measure of efficiency. The possible contamination of humans, wildfowl, animals, and insects by contacting the pond contents, and contamination of ground water by seepage have been considered to be potential hazards. (Ref. 1954-2) Although further studies are indicated, there have been no cases of such contamination reported by any State Health Department to date. Reductions in bacteria, as determined by coliform density (MPN), were greater than 99 per cent more than 50 per cent of the time and, except for one sampling period at two installations, were 95 per cent or greater at all times.

Future studies regarding the public health aspects have been noted. Other factors that merit further research include the determination of (1) more specific loading limits for different climates,

(2) practical optimum operating depths, (3) methods of achieving flexibility of depth and area at different times of the year, (4) a method of obtaining a clear (low algae content) effluent, (5) effect of mineral content of municipal water supply of community served by the stabilization pond, (6) procedures to minimize or eliminate possible odors during critical operating seasons, (7) economically feasible methods of sealing pervious bottoms and, (8) methods of inhibiting evaporation in arid regions.

SUGGESTED DESIGN CRITERIA

The following criteria for the design, construction, operation, and maintenance of sewage stabilization ponds are intended for use in the Dakotas or regions having similar climates. These criteria are discussed in Chapter V.

A. Design

1. Original construction should provide at least one surface acre per one hundred (100) persons served, including the population equivalent of any industrial wastes to be discharged to the sewer system. In terms of B. O. D., a combined loading of 20 lbs. per acre should not be exceeded. Due consideration should be given to possible future municipal expansion and/or additional sources of wastes when the original land acquisition is made.

2. The choice between the use of single cell and multiple cell ponds will be dictated on the basis of local conditions and downstream water use. Where a greater degree of treatment is necessary or desirable, one or more cells in series may be added to the primary cell; provided, however, that the primary cell should have a surface area equal to that set forth in A-1.

3. Where ponds of one or more cells follow some type of conventional primary treatment device, the requirements in A-1 may be reduced to compensate for the B. O. D. reduction in the pretreatment unit(s). However, the area of the first or primary cell following the pretreatment unit(s) should be not less than 75% of A-1.

4. The shape of all cells should be such as to produce a uniform perimeter. No islands, peninsulas or coves should be permitted.

B. Location

1. Ponds should be located approximately 1/2 mile from the city limits. Due consideration should be given the possible future expansion of the city when assessing this factor.

2. Ponds should be located approximately 1/4 mile from the nearest residence or habitation.

3. If practical, ponds should be located so that local prevailing winds will be in the direction of non-inhabited areas.

4. Locating ponds in watersheds receiving significant amounts of runoff water is discouraged unless adequate provisions are made for storm water to by-pass the ponds.

5. In locating ponds, preference should be given sites which will permit an unobstructed wind sweep across the ponds, especially in the direction of the local prevailing winds.

6. Proximity of ponds to water supplies and other facilities subject to contamination should be critically evaluated to avoid creation of health hazards or other undesirable conditions.

C. Embankments and Dikes

1. Compacted embankments of impervious materials should be constructed.

2. Minimum embankment top width should be 8 feet.

3. Maximum embankment slopes should not be steeper than:

a. Inner - 3 horizontal to 1 vertical.

b. Outer - 3 horizontal to 1 vertical.

4. Minimum embankment slopes should not be flatter than:
   a. Inner - 6 horizontal to 1 vertical.
   b. Outer - not applicable, except that significant volume of surface water should not enter the ponds.
5. Minimum free board should be 3 feet plus frost heave.
6. Minimum normal liquid depth should be 3 feet.
7. Maximum normal liquid depth should be not more than 5 feet.
8. Embankments should be seeded, except below the water line.

Alfalfa should not be included in seed mixtures since the long roots of this plant are apt to impair the water-holding efficiency of the dikes. Additional protection for embankments such as rip-rap may be necessary as soil conditions and pond size warrant.

D. Pond Bottom

1. The pond bottom should be as level as possible at all points.

Shallow or feathering fringe areas usually result in locally unsatisfactory conditions.

2. The bottom should be cleared of vegetation and debris. Organic material thus removed should not be used in embankment construction.

3. Soil formations should be relatively tight to avoid undue liquid losses through percolation or seepage. Soil borings to determine soil characteristics shall be made a part of preliminary surveys to select pond sites.

E. Influent Lines

1. The influent line into single-celled ponds should be essentially center-discharging. Influent lines into the primary section of multiple-celled ponds should be essentially center-discharging, but this does not apply to those cells following the primary cell in series operation.

2. Either upward or horizontal discharging influent lines may be used where the sewage is pumped to the pond. Horizontal inlets should be used for gravity flow. When upward discharging lines are used, the discharge end of the pipe should be located approximately one foot above the bottom of the pond and should not extend to such elevation that ice will damage the terminal structure during winter operations.

3. The end of the discharge line should rest on a suitable concrete apron with a minimum size of two feet square. Larger aprons and influent piping supports are suggested in cases where the soil is unstable.

4. Manholes or clean-outs are recommended where inlet pipe passes through the embankment.

5. Influent lines should be placed on or under the bottom. The use of exposed dikes carrying influent lines to the center of the pond should be prohibited, as such structures will impede circulation.

F. Interconnecting Piping and Overflows

1. Interconnecting piping and overflows should be of cast iron pipe or corrugated metal pipe of ample size. The use of frost proof overflow manholes for controlling liquid levels in the pond is encouraged if an influent line to the structure is provided and arranged so that overflows may be drawn from various levels.

2. Overflow lines should discharge onto concrete slabs. These lines should be vented if siphoning may be developed.

G. Miscellaneous

1. The pond area should be adequately fenced with a stock-tight fence.

2. Appropriate signs should be provided to designate the nature of the facility.

Chapter II

GENERAL INFORMATION

MECHANISM OF STABILIZATION

A sewage stabilization pond, as used in the Dakotas, is an excavation designed and constructed to receive raw or pretreated domestic sewage and some organic industrial wastes; in which stabilization is accomplished by several natural "self-purification" phenomena.

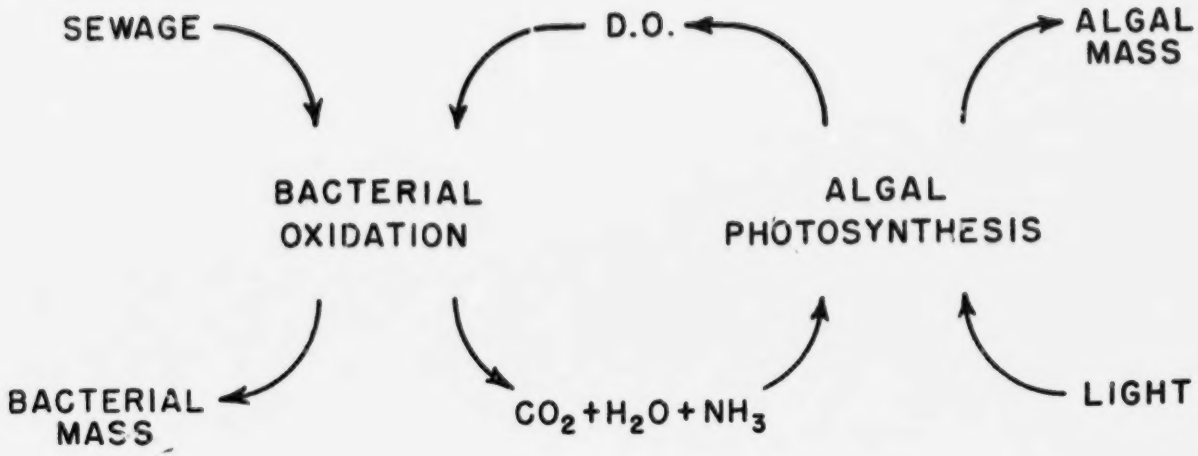
Sedimentation occurs immediately after the sewage enters the pond. Not only settleable solids, but suspended and even colloidal particles may be precipitated by the action of soluble salts which are concentrated by evaporation in summer and freezing in the winter. Subsequent benthic decomposition of the settled organic matter produces an inert residue and soluble organic nutrients which diffuse into the overlying water and are available for consumption by oxygen-producing algae. Dispersion of the benthic material is accomplished by wind action in the summer and, to a much lesser degree, by convection currents in the winter. Stabilization of the remaining colloidal and suspended matter is accomplished by simultaneous bacterial - algal interaction. See Figure 1.

The above functions are made possible during open water seasons by sunlight and wind; the sunlight furnishing the energy for photosynthesis and possibly germicidal action, and the wind accomplishing a mechanical distribution of dissolved oxygen and essential nutrients.

Ice cover is a barrier to both light and wind. When snow is present, light penetration is further impaired. Consequently, stabilization ponds become anaerobic soon after ice formation. Accompanying low temperature also slows down bacterial action. At the same time salts and other sewage constituents become more concentrated under the ice of non-overflowing installations, not only from the continual application of raw sewage, but also by exclusion from ice in the process of freezing. Therefore, melting ice can be expected to provide good quality dilution water in the spring.

HISTORY

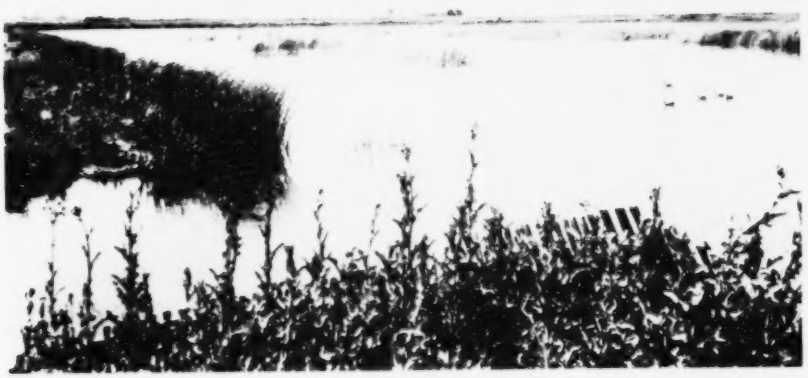
In the United States, the first published observations of sewage stabilization by photosynthesis were made in the Southwest (Reference: 1946: (1), (2), (3), and (6),) where sunlight and open water surface are available all year. The City of San Antonio is reported (Reference: 1954: (7),) to have utilized the stabilization pond principle as early as 1901. A clogged sewage seepage gravel



STABILIZATION MECHANISM

FIGURE 1

FIGURE 2



OLDEST "LAGOON" IN THE DAKOTAS
FESSENDEN, NORTH DAKOTA

A DIKED SLOUGH THAT HAS BEEN
RECEIVING RAW SEWAGE SINCE 1928

bed at Santa Rosa, California, in 1924 made possible the first observations of photosynthetic stabilization in that State. Subsequent experience in both States has resulted in such favorable reaction that there are now more than 250 installations in the Southwest.

In the Northern Plains area, raw sewage from Fessenden, North Dakota, has been discharged to a slough west of the city since 1928, but the first deliberately designed stabilization pond was constructed at Maddock, North Dakota, in 1949.

Favorable results of studies at the Maddock installation led the North Dakota Department of Health to endorse their use as a legitimate method of sewage treatment in that State. Subsequent acceptance of stabilization ponds by neighboring States has resulted in an accelerated rate of construction. Currently, there are 136 stabilization ponds in the Missouri Basin, of which more than 70 are in the Dakotas.

Appendix E contains descriptive data on existing installations in North and South Dakota.

The present status of sewage stabilization ponds in the Dakotas can best be stated by the organizations most familiar with their functioning and most cognizant of the sanitary significance of installations

serving communities in their respective States - the State Health Departments:

> North Dakota: "Sewage lagoons are the effective and economical answer to community disposal problems." (May 10, 1954)
>
> South Dakota: "The use of stabilization ponds as a method of sewage treatment has progressed to the point that there is little controversy as to the application of this process for sewage treatment." (November 1955)

OBJECTIVES

The objectives of the present investigation were to:

1. Give better definition and understanding to the stabilization mechanism. Ponds designed and constructed in accordance with tentative design standards established by the Dakota State Health Departments have performed very satisfactorily. In order that these tentative design standards might be stated more positively and permanently, better understanding of the complex interaction of physical, bacterial and biological forces was needed. Research in the Southwest has been improving the status of understanding of the basic mechanism of photosnythetic stabilization. It is hoped that this study of existing installations in the Dakotas, where ice cover prevails for over one-third of the

calendar year, will give better understanding to the factors affecting the stabilization mechanism under these climatic conditions.

2. Evaluate variables in design, loading and season. Such an evaluation must necessarily take cognizance of all factors as they actually exist - as measured at existing sites rather than from plans and related descriptive data.

3. Point direction and objectives of experimental studies. The broad coverage of this field survey of the Dakota stabilization ponds will result in a need for detailed "following through" on various ideas and interpretations that will naturally evolve. Testing them and checking their applicability in other climatic areas will be carried out in experimental installations where operating conditions can be controlled.

4. Develop interim criteria for the geographic area. This has already been done by both States, the most recent having been written by South Dakota. This joint report should make a set of design criteria valid for the entire geographic and climatic area.

INITIATION OF THE STUDY

1. Sewage stabilization ponds in the Missouri Basin have been a subject of studies by the Departments of Health of North and South

Dakota and the U. S. Public Health Service Regional Office at Kansas City since 1950. These were short term studies, limited by time and personnel and were the basis of planning for a long term seasonal investigation.

2. Need for such an investigation was discussed by the Engineering Section, Missouri River Basin Health Council (Fourth Annual Conference on Sanitary Engineering held at Lawrence, Kansas, January 8, 1954).

3. The 53rd Annual Conference of State and Territorial Health Officers, (December 10, 1954) prepared the following resolution (Recommendation No. 9, Sewage Treatment by Lagoons):

> "That the Public Health Service investigate sewage lagoons as a means of treating raw municipal sewage to determine the various design criteria, their effectiveness and detail of operation."

4. Cooperative relations were established for joint participation by North Dakota, South Dakota, Region VI Public Health Service and the Robert A. Taft Sanitary Engineering Center.

FIELD PROGRAM

1. Because of the influence of seasonal changes upon the stabilization processes, a comprehensive study of five selected installations was planned so as to evaluate winter, spring, summer and fall conditions during 1955.

2. The geographic position of the five ponds which were studied are shown in Figure 3.

3. A stabilization pond was constructed at Kearney, Nebraska, in May 1954. The installation was observed closely by the Region VI Office. (Reference: 1956: (7).)

4. Flow pattern of raw sewage entering an ice-covered pond was established by using radioactive iodine as a tracer. The study was made at Philip, South Dakota. (Reference: 1956: (8).)

5. Selection of five Dakota ponds to be studied during each of the four seasons was based on the goal of obtaining as wide a range of loading and design conditions as possible:

Kadoka, South Dakota

Irregular shape and depth; subject of complaint by certain residents.

Wall, South Dakota

Most shallow of all Dakota installations.

Lemmon, South Dakota

Deepest of all Dakota installations - also largest population served at time study was initiated.

Maddock, North Dakota

The only pond with three cells in series.

Wishek, North Dakota

Regular shape and depth; completely enclosed by dikes.

6. Three types of observations were made throughout the study:

Physical:

Raw sewage and effluent flows

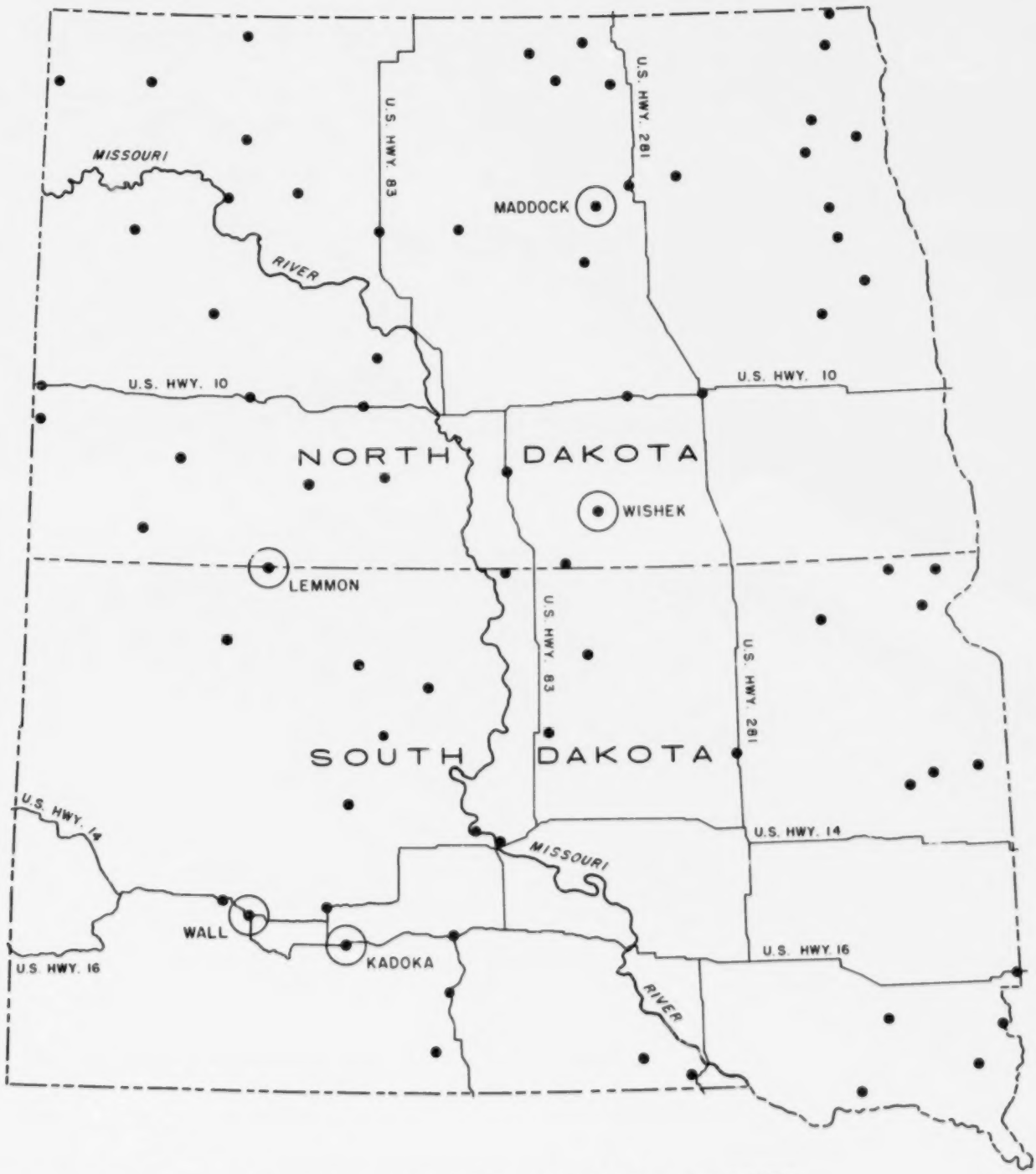
Wind velocity and direction

Air and pond temperature

Light intensity

Measurement of structural features, and

Volume of contents



LOCATION OF DAKOTA STABILIZATION PONDS

FIGURE 3

18-B

Chemical:

- pH
- Dissolved Oxygen
- Alkalinity
- Biochemical Oxygen Demand
- Nitrogen
  - Total
  - Ammonia
  - Nitrite
  - Nitrate
- Phosphate
  - Total
  - Ortho
- Sulfides
- Chlorides
- Turbidity
- Suspended Solids

Biological:

- Plankton, coliform bacteria (MPN)
- Bottom organisms
- Special samples and tests

7. Chronology:

January 20 - February 12, 1955

Winter survey: three consecutive sample days at each pond. Analyses made in South Dakota Mobile Laboratory for all sites except Wishek, North Dakota, from which samples were carried to the North Dakota Laboratory in Bismarck immediately after collection.

March 11 - March 13, 1955

Study of flow pattern under ice at Philip, South Dakota, by use of radioactive isotope.

March 24 - April 6, 1955

Observation of transition from ice cover to open water at Kadoka, South Dakota

April 22 - May 15, 1955

Spring survey; same procedure as winter survey. South Dakota Mobile Laboratory used for Kadoka, Wall and Lemmon samples, and North Dakota's Laboratory at Bismarck used for Maddock and Wishek samples.

July 18 - August 21, 1955

Summer survey; in addition to repeating procedures of preceding seasons, special biological and soil studies were made. The South Dakota Mobile Laboratory was supplemented with U. S. Public Health Service Mobile Laboratory.

October 31 - November 2, and November 7 - November 12, 1955

Fall survey; one day sampling at all ponds except Wishek, which could not be reached due to heavy snow and icy roads. Three of the four installations studied were sampled as ice was forming on the surface.

March 2 - June 2, 1956

Winter-spring transition from anaerobic condition under ice to aerobic condition with open water and prolific algal growths.

8. Soil Studies:

A critical requirement for successful stabilization pond operation is that the bottom and sides be relatively impermeable. A seepage rate of 1/4 inch per day from an

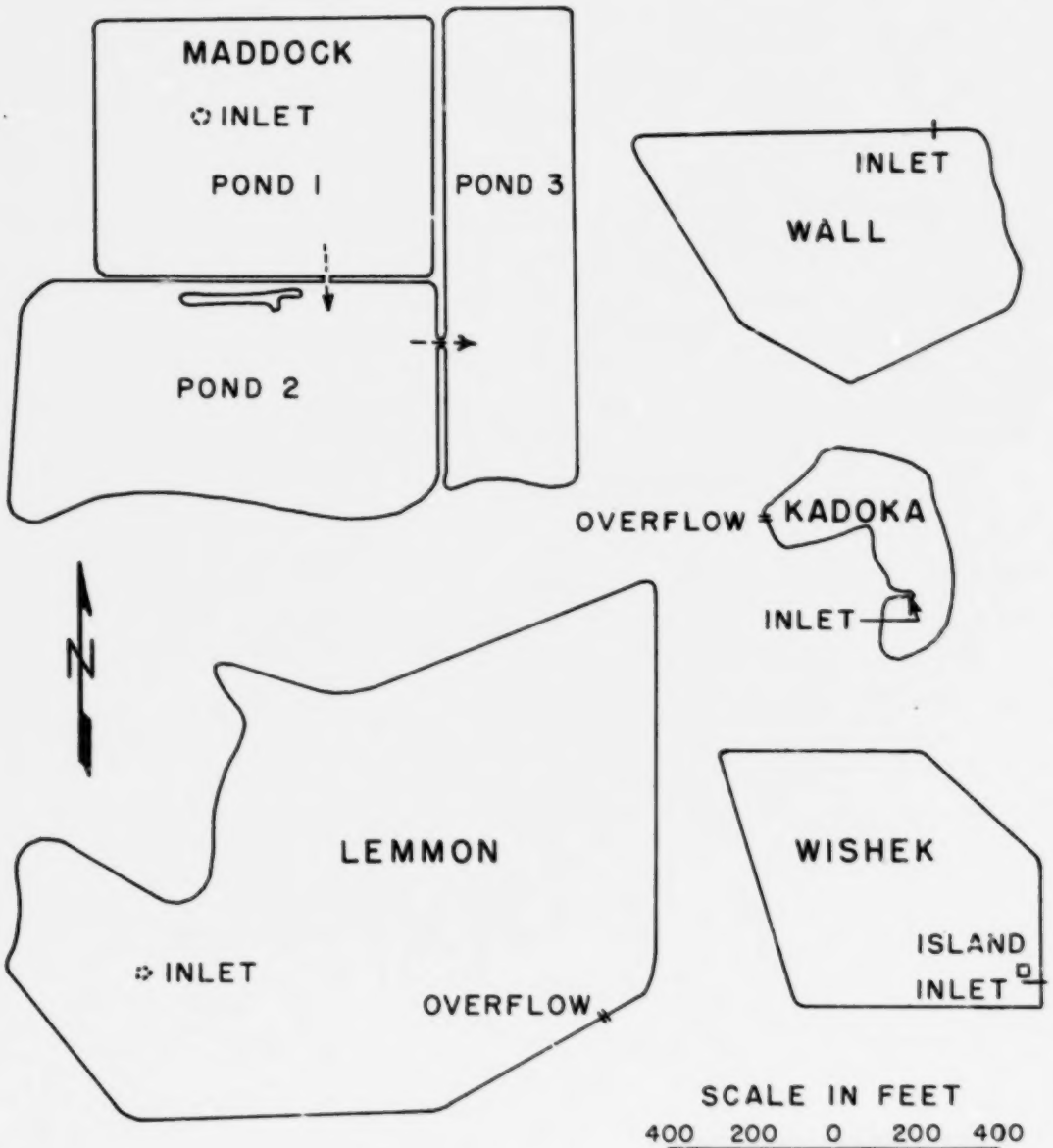
area of one acre would remove more water than could be supplied by 100 persons contributing 50 gallon per capita daily. Excessive seepage could thus prevent an optimum operating depth from being attained.

Dikes and embankments must not only be impermeable, but must also be resistant to erosion from waves and rainfall. Limited studies were conducted on the soil conditions at several Dakota installations during the summer of 1955.

PROCEDURES

Plan views of each of the five ponds are shown in Figure 4. Inlets, outlets, location of sampling stations, shape, and relative sizes are illustrated.

Laboratory analyses were performed as close to the respective sites as possible. A mobile laboratory was operated in Philip, South Dakota, to handle samples collected at Kadoka and Wall, South Dakota. It was then moved to Lemmon, Maddock and Wishek during the first (winter) investigation. It was not used at the latter two sites for the subsequent spring, summer and fall investigations, since the State Laboratory at Bismarck was centrally located and accessible for direct transportation of samples.



LOCATION	KADOKA, S.D.	LEMMON, S.D.	MADDOCK, N. D.			WALL, S.D.	WISHEK, N.D.
			Pond 1	Pond 2	Pond 3		
Surface Area (acres)	3.0	27.1	11.7	12.3	8.0	8.9	7.8
Depth, Max. (feet)	7.7	14.0	5.0	3.6	5.7	2.2	3.8
Depth, Ave. (feet)	4.4	5.7	4.0	2.8	4.4	1.2	3.0

FIGURE 4

Sample collectors determined pH, dissolved oxygen and temperature in the field immediately after the samples were collected. Samples transported to the mobile or fixed laboratories were analyzed for alkalinity, B. O. D., ammonia and nitrite nitrogen, orthophosphate, sulfides, chlorides, turbidity, suspended solids and coliform (MPN) bacteria.

Portions of each sample were preserved with sulfuric acid and transported to Cincinnati for total organic nitrogen, nitrate nitrogen, and total phosphate analyses. Because there was an unavoidably long delay before these analyses could be made, the reliability of results was questionable, and they have not all been included in the data tabulation.

Chapter III

TREATMENT OBTAINED

REDUCTION OF BACTERIA

Bacterial reductions have been evaluated in terms of Most Probable Number (MPN) of coliforms. Maximum and minimum per cent reductions given below were based on the difference of MPN (geometric mean of three day's analyses) for the raw sewage and the maximum and minimum MPNs of all stations. A reduction of more than 99 per cent was accomplished during more than fifty per cent of the time and, except for one sampling period at two installations, was 95 per cent or greater at all times. Table 1 shows the reductions for all seasons at the five installations studied.

CHEMICAL QUALITY

1. B. O. D.

Reduction of 5 day, 20°C B. O. D. through the four seasons ranged from 43.6 per cent to 98.4 per cent. The minimum figure was obtained at Wall, South Dakota, under ice where, due to the shallowness of the liquid beneath the ice, it was difficult to obtain a sample without picking up bottom material. Furthermore, the ice formation had concentrated the original pond contents into a much smaller volume. The

Table 1

SEASONAL REDUCTION IN COLIFORM DENSITY

Season and Sample		Kadoka	Wall	Lemmon	Maddock	Wishek
Winter	(Influent*	23,700	13,420	19,000	32,000	60,300
	(Effluent*	1-24	420-2200	20-46	580-1330	1430-3380
	(% Reduction	>99.9	83.6-96.8	99.7-99.8	95.9-97.4	97.8-99.2
Spring	(Influent*	43,000	3,170	4,580	2,580	19,950
	(Effluent*	120-230	4-13	21-43	19-27	45-250
	(% Reduction	99.5-99.8	99.6-99.9	97.3-99.1	98.8-99.2	98.6-99.8
Summer	(Influent*	101,000	63,240	34,900	32,200	42,000
	(Effluent*	43-240	40-340	15-93	80-298	234-1710
	(% Reduction	99.6-99.9	99.4-99.9	99.8-99.9	99.1-99.7	95.9-99.6
Fall	(Influent*	46,000	46,000	2,300	930	-
	(Effluent*	430	240-460	43-930	23-43	-
	(% Reduction	99.2	99.1-99.6	59.5-98.1	95.4-97.4	-

* MPN x 10^3/100 ml.

minimum B. O. D. reduction at all other locations was 70. 0 per cent which also occurred during ice cover. During open water conditions, pond and effluent samples contained large numbers of algae which join with bacteria and other organisms in utilizing oxygen during the incubation of B. O. D. samples in darkness. Such B. O. D. values are not strictly comparable to those of the influent sewage, although they were of necessity used in deriving the B. O. D. reductions shown in Table 2. Also, they do not reliably indicate the probable effect upon the receiving stream, as the algae may actually produce oxygen under proper light conditions.

Concentration of B. O. D. and chloride in p. p. m. at all stations in two ponds during the four seasons is shown graphically in Figure 5. These graphs reveal (1) the uniform quality of all samples collected more than 50 feet from the inlet; (2) the concentration of dissolved substances in non-overflowing ponds under ice; (3) the increase of dissolved salts in successive ponds of a multiple-unit non-overflowing installation such as Maddock and (4) the change in concentrations by seasons.

At the Kadoka and Lemmon ponds, which are provided with overflow structures, B. O. D. reductions were calculated in pounds. At Kadoka, the mean reduction during spring, summer and fall was 92

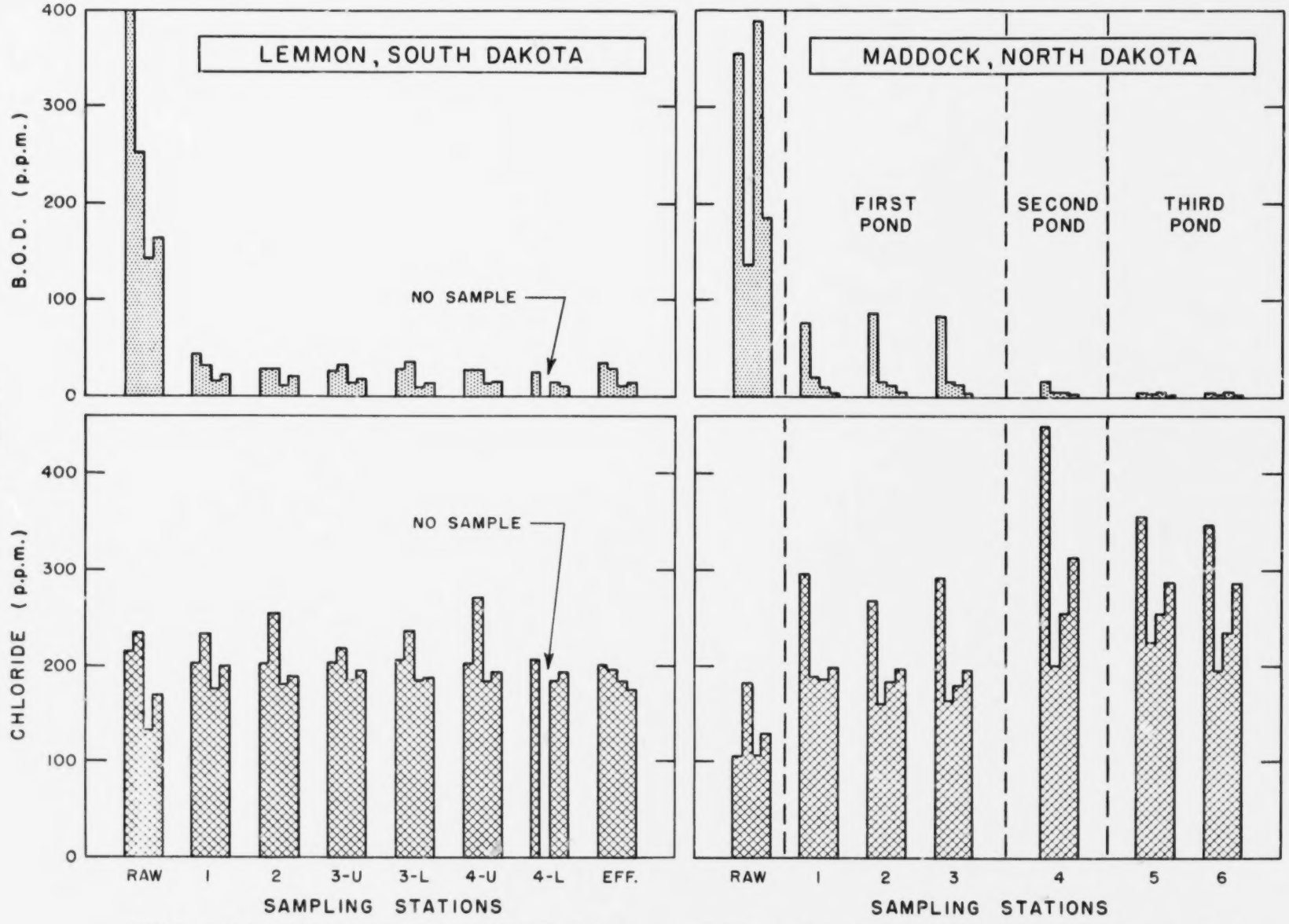


FIGURE 5

TWO ANALYSES AT ALL STATIONS WINTER, SPRING, SUMMER & FALL, 1955

per cent. At Lemmon, it was 99.3 per cent during the summer. These percentage reductions are obtained partly by seepage and evaporation losses, which are indicated by the low rates of overflow. At Lemmon, the volume of pond overflow was only ten per cent of the raw sewage inflow, while at Kadoka it was close to fifty per cent. It should be noted that the B. O. D. concentrations at sampling stations located within the pond itself are not significantly different from the effluent sample even though some of the sampling stations were relatively close to the inlet.

Table 2

SEASONAL PER CENT REDUCTION IN B. O. D. CONCENTRATION

Season	Kadoka	Wall	Lemmon	Maddock [1/]	Wishek
Winter	96.2	43.6	91.2	76.8	70.0
Spring	88.0	87.2	88.4	88.2	73.8
Summer	87.0	88.5	93.0	97.2	89.0
Fall	86.2	85.4	92.8	98.4	-

[1/] First cell only

The B. O. D. reductions shown in Table 2 represent treatment accomplished in a single pond. At the Maddock installation, which consisted of three ponds arranged in series, the B. O. D. is further reduced in each succeeding pond. Here, there is no overflow, and seepage and evaporation losses balance the applied sewage and precipitation.

2. Suspended Solids and Turbidity

Reduction in suspended solids is affected by two antagonistic processes; deposition on the one hand, and production of free floating algae on the other. During the winter, when algal production is at a minimum, suspended solids were reduced from 68 to 93 per cent. In contrast, during open water seasons, mean effects on suspended solids ranged from a reduction of 68 per cent to an increase of 112 per cent.

3. Nitrogen

Ammonia and nitrite nitrogen analyses were performed in the mobile laboratory shortly after collection. The following table shows the average of ammonia concentrations found in the five ponds studied during each of the four seasons of 1955. Decrease in concentration of ammonia is attributable to dilution by melting ice, bacterial oxidation, and assimilation by algae.

Table 3

AMMONIA NITROGEN CONCENTRATION, PPM

Season	Kadoka	Lemmon	Wall	Maddock	Wishek
Winter	25	8	60	20	60
Spring	19	2	9	4	32
Summer	4	4	1	1	1.4
Fall	3	1	0	22	--

4. Phosphorus

Table 4 shows the concentration of total phosphorus as phosphate and orthophosphate in the influent, effluent and pond samples. Except for the winter investigation at Wall, the concentration in the pond contents or effluent always was less than that in the raw sewage. Orthophosphate is assimilated during algal growth and accordingly may be expected to fluctuate in concentration. Total phosphorus generally was greater during winter than during open water seasons. It seems likely that decreases in total phosphorus during the period of rapid algal growth result from loss of algae from the medium through deposition and overflow.

Table 4

SEASONAL CONCENTRATIONS OF TOTAL PHOSPHORUS (AS PHOSPHATE) AND ORTHOPHOSPHATE

Sample	Winter		Spring		Summer		Fall	
	Total	Ortho	Total	Ortho	Total	Ortho	Total	Ortho
Kadoka, S. D.								
Raw(Inlet)	105.0	27.0	97.0	0.0	80.0	38.0	---	---
Effluent	44.0	26	58.0	4.0	25.3	8.0	---	---
Av. in Pond	48.2	27.8	53.8	2.7	28.6	11.2	4.40	---
% Reduction	58.1	37.0	44.5	---	64.2	70.5	---	---
Lemmon, S. D.								
Raw	45.4	27.0	51.6	1.0	39.3	22.0	31.2	20.0
Effluent	16.0	10.0	18.8	0.7	6.4	4.0	13.6	0.75
Av. in Pond	17.2	12.3	20.8	1.0	7.3	3.5	12.4	0.75
% Reduction	62.1	54.4	59.7	---	81.4	84.1	60.2	96.2
Wall, S. D.								
Raw	63.0	28.0	65.0	5.0	51.3	23.0	---	---
Av. in Pond	72.8	54.5	50.8	5.2	16.1	4.2	30.0	---
% Reduction	15.5	94.6	21.8	4.0	68.6	81.7	---	---
Wishek, N. D.								
Raw	62.7	65.0	31.2	2.0	43.0	19.0	---	---
Av. in Pond	57.4	54.3	25.6	1.5	8.2	5.0	---	---
% Reduction	18.5	16.5	17.9	25.0	80.9	73.7	---	---
Maddock, N. D.								
Raw	53.4	36.0	32.8	1.0	51.1	30.0	---	45.0
Av. in#1 Pond	26.1	27.3	21.1	0.8	6.0	8.0	---	20.1
% Reduction	51.1	24.2	35.7	20.0	88.2	73.3	---	55.3
Av. in#2 Pond	16.3	18.0	7.8	0.5	3.2	5.0	---	4.6
% Reduction	37.5	34.1	63.0	37.5	46.7	37.5	---	77.1
Av. in#3 Pond	4.6	4.0	4.0	0.7	1.2	5.0	---	1.2
% Reduction	71.8	77.8	48.7	40.0	62.5	---	---	73.9

5. Chloride

Chloride ions are not affected appreciably by natural chemical or biological action, but chloride concentration is increased by evaporation and decreased by dilution. Removal can thus be accomplished only by seepage or effluent discharge from the pond.

None of the five ponds studied were amenable to accurate "balance" of chloride content. Kadoka and Lemmon, the two overflowing ponds, had an effluent that varied in quantity with weather factors, especially wind direction and velocity. Effluent flow would increase when the wind was toward the outlet and decrease when the wind was away from the outlet.

At the time of the spring study, the Kadoka pond contained approximately 5800 pounds of chloride ion; summer, 5600, and fall 6400 pounds. The increment added between spring and fall, based on average difference between inlet and outlet, was 500 pounds. When added to the 5800 pounds present during the spring study, the total content at the time of the fall study should have been 6300 pounds as compared with the actual 6400 pounds.

In Lemmon, the total chloride content at the time of the spring survey was 98, 700 pounds and during the fall study, 80, 220, a decrease

of 18,480 pounds. Based on raw vs. effluent, the total content of chloride ion should have increased by 32,000 pounds. The periods of investigation were obviously too short to serve as a basis for extrapolating annual increments of the pond contents.

Accurate water level determinations were not made on the non-overflowing ponds at Wall, Maddock and Wishek, so any attempt to ascertain the total content of each is not feasible. A differential of only one inch in water level would cause the following changes in volume:

	Gallons	Pounds
Wall	242,000	2,016,000
Maddock (first cell)	317,000	2,649,000
Wishek	212,000	1,766,000

6. Alkalinity - pH - Dissolved Oxygen

Alkalinity, pH and dissolved oxygen content of a stabilization pond are all related to algal activity. The range of values of each determination during the seasonal investigation is shown in Table 5. Except for Kadoka, all installations reflected the low level of algal activity during the period of ice cover. Dominant anaerobic decomposition results in lower pH values and corresponding lower

Table 5

SEASONAL RANGES OF ALKALINITY, pH, AND DISSOLVED OXYGEN VALUES DURING 1955

Season	Alkalinity P.	Alkalinity M. O.	pH	D. O.	Temp. °C
			Kadoka, S. D.		
Winter	0-46	791	8.2-8.5	0-0	
Spring	0-0	682	7.6-8.3	0-16.0	13-20
Summer	0-198	685	7.4-9.1	0-23.5	25-32
Fall	70	935	8.4-8.5	0-0	
			Wall, S. D.		
Winter	0-0	1200	7.0-8.2	0-0	
Spring	155-195	544	10.0-11.2	2.1-39.8	7-25
Summer	130-175	547	9.1-9.5	0-28.3	16-33
Fall	100-115	491	9.5-9.6	2.2-5.1	
			Lemmon, S. D.		
Winter	36-67	853	8.3-8.7	0-6.8	
Spring	8-150	847	8.9-9.4	11.9-16.9	12-15
Summer	58-192	585	9.2-9.7	2.1-42.0	21-30
Fall	90-140	780	8.9-9.0		
			Maddock, N. D. (1st Pond)		
Winter	0-0	900	8.0-8.2	0-0	
Spring	100-175	585	8.9-9.3	9.8-24.2	9-14
Summer	85-125	611	8.6-9.3	0-15.8	19.5-30
Fall	50-60	668	8.2-8.3	7.8-9.4	
			Maddock, N. D. (2nd & 3rd Ponds)		
Winter	28-88	840	8.1-8.7	0 (#2)-11.6 (#3)	
Spring	10-195	495	8.5-8.9	9.8-24.2	
Summer	75-110	493	8.4-9.6	1.0 (#2)-7.6 (#3)	
Fall	132-145	462	9.2-9.5	12.1-12.2	
			Wishek N. D.		
Winter	0-0	771	7.5-7.7	0-0	
Spring	65-100	386	8.9-9.7	4.8-37.8	12-28
Summer	20-65	287	8.4-9.5	0-32.0	21-32.5

phenolphthalein alkalinity, but this lowering effect is offset somewhat by the buffering action of the more concentrated total alkalinity under ice. In no case did the pH drop below 7.0.

During spring, the highest concentration in dissolved oxygen occurred in the shallowest installation (Wall, S.D.) as a result of intense photosynthesis. In the summer, apparently due to vulnerability of the algae to widely fluctuating temperature in the shallow pond, algal density decreased sharply and the photosynthetic activity here was less than at Lemmon where algal density remained more uniform.

7. Sulfides

Table 6

SULFIDE CONCENTRATIONS, PPM

Season	Kadoka	Lemmon	Wall	Maddock Pond #1	Wishek
Winter	36.2	0*	54.0	117	75
Spring	1.3	0	0	0	0
Summer	5.9	0	0	0	0
Fall	1.2	0	0	0	---
Sulfate in Municipal Water Supply	1038	17.4	362	244	52

* One near-bottom sample had 16 ppm, but is not representative of pond's sulfide content.

The presence of sulfides in a sewage stabilization pond is indicative of the anaerobic decomposition of organic matter. Their presence under ice was to be expected. Only the Kadkoa pond continued to produce sulfides through the open water seasons; Kadoka was the most heavily loaded (23 pounds B. O. D. per acre) and had the highest concentration of sulfate in the municipal water supply. Field observations to date have not made the cause of sulfide production apparent. A new pond with greater area has been constructed at Kadoka; further studies may determine the cause of sulfide production in the former pond.

PHYSICAL QUALITY

Laboratory determination of color was not made. In general, however, apparent color of the pond contents, as observed from the banks or in a sample bottle, was a good criterion of the relative condition of the pond. A rich green color indicated a good aerobic daytime balance; a dark, clear appearance indicated an anaerobic condition. Effluent from a photosynthetically active single pond installation may be expected to be green.

Removal of this green color should be possible by utilizing multiple cells in series. This was observed at Maddock, where the first pond was green, and the second and third ponds clear and colorless

during summer and fall. Higher organisms found in these secondary ponds may be credited with consuming the algae and thus removing the color. This activity occurred in a localized area at Maddock at the point where the effluent from the first pond entered the second pond. Apparently the death and decomposition of the higher organisms adds only a negligible load in the process of being stabilized.

Except for the period of transition from ice cover to the establishment of a typical algal population, odors are generally absent. This was the case at all ponds investigated except Kadoka, discussed above, under sulfides (page 34).

Floating matter normal to raw sewage was seldom seen on the surface or banks of the stabilization ponds investigated. Weeds or shallow banks were the only factors that would retain the materials in sight of the shore observer.

Chapter IV

FACTORS THAT AFFECT THE PROCESS

SEWAGE QUALITY AND QUANTITY

Strength of sewage is generally stated in terms of its 5-day, 20°C. biochemical oxygen demand (B. O. D.) The per capita daily contribution of the five communities served by the ponds investigated is shown in Table 7.

Table 7

RAW SEWAGE

Place	Strength, # B. O. D. per capita per day	Flow, Gallons per capita per day
Kadoka	0.118	36
Wall	0.112	45
Lemmon	0.071	48
Maddock	0.147	68
Wishek	0.082	46

Based on these figures, 100 persons could contribute 3600 to 6800 gallons of sewage daily, with a strength from 7.1 to 14.7 pounds of B. O. D. These variations might be expected to produce correspond-

ing differences in the operation of ponds serving each community at a loading of 100 persons per acre. None of the five ponds studied was loaded at this specific rate. Population served per acre varied from 62 (Wall) to 195 (Kadoka); based on sewage strength (pounds B. O. D. per acre) the loadings varied from 6. 8 to 22. 9. The pond at Wall recovered quickly after ice melt and operated without odor during all seasons. The one at Kadoka recovered slowly in the spring and produced odors during parts of every season.

TOXIC MATERIALS

Although no specific toxic materials were known to be present in the raw sewage applied to the ponds subjected to the seasonal study, concentration of certain constituents (such as sulfates) during ice cover may possibly have some inhibiting effect on the establishment of algal growth in early spring. This problem was not explored during the Dakota study.

SIZE

Size (surface area and volume) affect the following functions:

(1) Dilution

(2) Exposure to sunlight

(3) Detention time

(4) Wave production

(5) Concentration by evaporation

(6) Liquid loss through seepage

(7) Mixing by natural forces

The interrelationship of volume of applied sewage and rainfall, to seepage, evaporation and effluent flow results in definite limitations on size, especially where loss by evaporation and seepage is considerably greater than rainfall. Since the photosynthetic production of oxygen by algae is the key to successful aerobic stabilization, optimum surface exposure to sunlight should be incorporated in the pond design. However, where no effluent is to be discharged, cognizance of seasonal fluctuations in water level is mandatory. Figure 4 shows the shapes and size of the five ponds investigated.

LIGHT

Light is important in three different ways. First, regional variations in annual solar radiation which differ with latitude, elevation, and cloud cover, will determine how well a stabilization pond will operate in a given location. Second, seasonal changes in daily solar radiation suggest the seasonal difficulties to be expected. Finally, penetration of incident light determines how much of the pond volume will participate in oxygen production.

Because photosynthesis is such an important factor in stabilization pond operation, considerable time and effort was devoted to studying this phenomenon. Light penetration into the ponds was measured during each season, using matched surface and submerged photronic cells sensitive between 4200 and 7000 Angstroms. Figure 6 shows light remaining at various depths in three South Dakota bodies of water. Because of the extremely dense growths of algae, light penetration in stabilization ponds is strikingly less than in most bodies of water which have been measured. Murdo Lake, a water supply reservoir for Murdo, South Dakota, falls within the general range of light extinction commonly reported for lakes, and absorbs 99 per cent of incident light in the upper 23-1/2 feet. In contrast to this, the layer absorbing 99 per cent of the light in the pond at Kadoka is only 6 inches thick. This difference in light absorption with depth, results for the most part from the difference in algal density. This is reflected by chlorophyll concentrations as shown in Figure 6.

The layer absorbing 99 per cent of incident light, sometimes called euphotic zone, is significant in any body of water as the stratum in which all appreciable photosynthesis occurs. With reference to stabilization ponds, it therefore indicates the proportion of volume

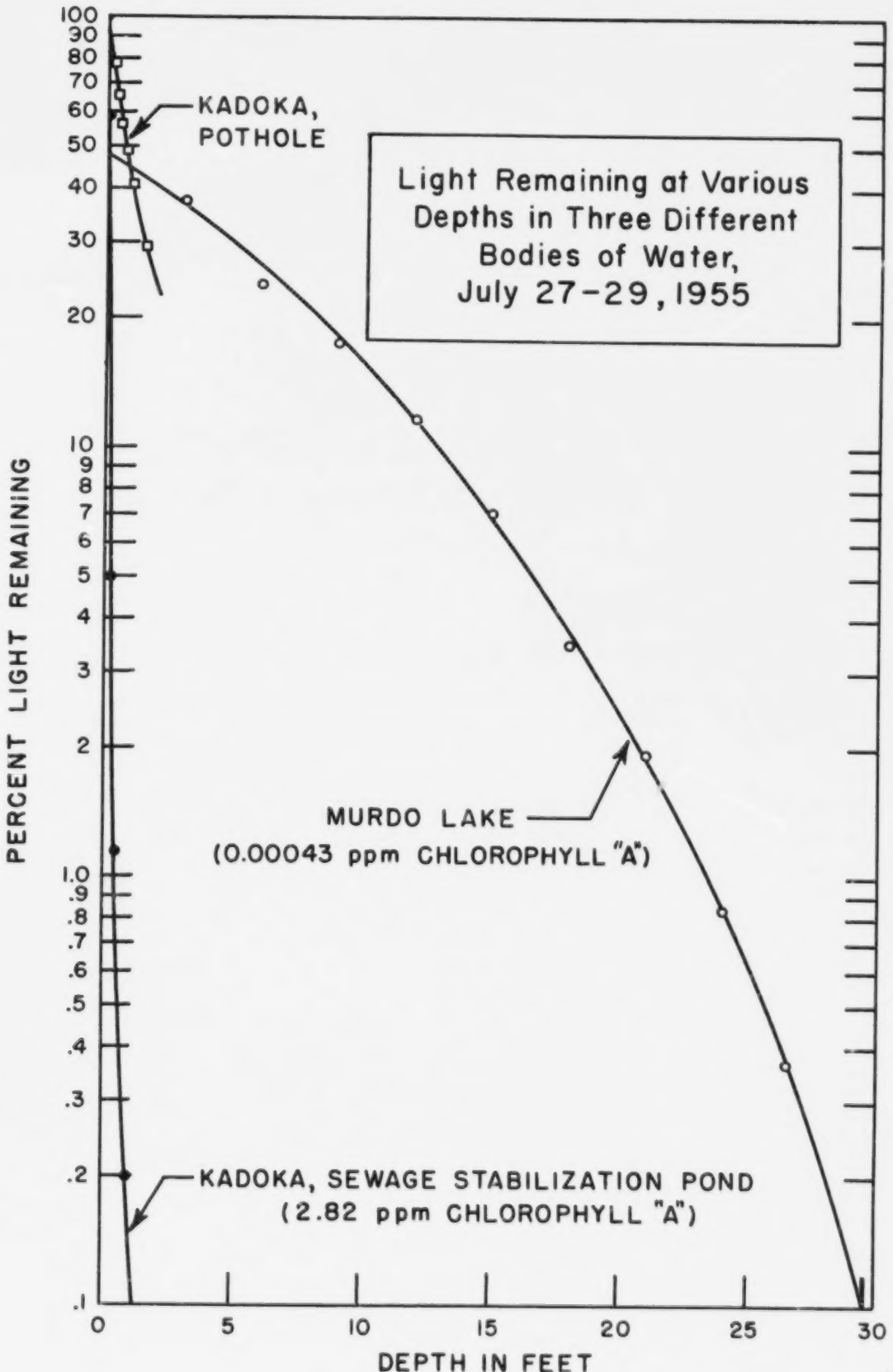

Light Remaining at Various Depths in Three Different Bodies of Water, July 27-29, 1955
KADOKA, POTHOLE
MURDO LAKE
(0.00043 ppm CHLOROPHYLL "A")
KADOKA, SEWAGE STABILIZATION POND
(2.82 ppm CHLOROPHYLL "A")
PERCENT LIGHT REMAINING
100
30
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
10
15
20
25
30
DEPTH IN FEET

FIGURE 6

40-B

that produces oxygen by photosynthesis, and suggests the decreasing aeration benefit to be expected from each additional increment of depth.

The light absorption pattern varies with each sewage stabilization pond, suggesting an individuality that can be expressed in terms of the depth at which 10 per cent and 1 per cent of the surface light remains. These values are given in Table 8 for five ponds and for Murdo Lake. Also shown is per cent light transmission through ice and snow. These latter figures agree well with measurements through ice on southeastern Michigan lakes. (Ref. 1945-(1))

Oxygen production at the light intensities prevailing at various depths was measured in several ponds. To do this, pond samples in glass-stoppered B. O. D. bottles were suspended at selected depths in the pond. Half the bottles were kept dark by covering them with two layers of aluminum foil. Oxygen change occurring during the test period was used to determine mean hourly photosynthetic production and total respiratory use of oxygen.

Diminishing photosynthesis with depth, as determined in the Lemmon pond, is shown in Table 9. Oxygen production decreased rapidly with depth. The rate at 24 and 38 inch depths was 14 per cent

Table 8 APPROXIMATE DEPTH TO WHICH LIGHT PENETRATES WATER, ICE, AND SNOW

Place and Season	10% of Surface Light (water)	1% of Surface Light (water)	Light Transmission through Ice and Snow		
			Mean Ice Thickness	Mean Snow Thickness	Mean Light Transmission-%
Kadoka, South Dakota					
Spring	5.9 inches	12.5 inches			
Summer	5.5	16.0			
Fall	5.0	11.5			
Winter	---	---	10.5 inches	0.9 inches	6.5
Wall, South Dakota					
Spring	2.0	4.0			
Summer	7.0	16.5			
Fall	2.0	6.0			
Winter	---	---	10.0	0.0	20.4
Lemmon, South Dakota					
Spring	7.0	16.5			
Summer	12.9	27.5			
Fall	4.0	9.5			
Winter	---	---	12.7	0.0	55.5
Maddock, North Dakota					
Spring	5.5	12.0			
Summer	10.0	23.0			
Fall	7.5	15.5			
Winter	---	---	25.9	3.0	1.2
Wishek, North Dakota					
Spring	3.0	7.0			
Summer	6.5	15.5			
Fall	3.5	8.5			
Winter	---	---	17.0	3.0	1.2
Murdo Lake, South Dakota					
Summer	158	282			

Table 9

OXYGEN PRODUCTION AT DIFFERENT DEPTHS DURING A FIVE-HOUR PERIOD

Lemmon, S. D., August 12, 1955

% Surface light	Light intensity, approx. F. C.	Depth, inches	D. O. change, ppm		Oxygen production ppm per hour	Respiration ppm per hour
			Light bottles	Dark bottles		
19.0	1050	10	+12.6	-2.1	2.9	0.4
3.1	167	24	0.0	-2.1	0.4	0.4
0.5	27	38	- 1.4	-2.0	0.1	0.4
0.07	3.8	53	- 1.6	-1.8	0.04	0.4

Determinations were made in triplicate.

and 3-1/2 per cent, respectively, of what it was at 10 inches. Respiratory use of oxygen was essentially the same at all depths. The 1 per cent light level occurred at 32.5 inches, and oxygen production at this depth was estimated at 0.2 ppm/hr. or only one half the rate of respiratory use.

This production rate, which was measured during the brighter part of the day, does not persist throughout the daylight period. Other tests (Table 10) showed that the production rate varied from 17.8 pounds per acre per hour at mid-morning, to only one-quarter pound during early evening. Although diminishing light intensity is an important factor in limiting photosynthesis, shortage of carbon dioxide may be partly responsible also.

During this same period, total respiratory use varied only slightly in spite of using a separate pond sample for each test period. The oxygen used in total respiration, as shown in Table 10, is that required for the needs of all living organisms in the pond, including bacteria which attack not only the incoming sewage, but also dead algal cells and any other decomposable organic matter that may be present. The direct influence of the incoming sewage upon the respiratory rate is not clearly discernible; however, if sewage loading is simply converted to pounds of ultimate demand per acre per hour,

Table 10

DISSOLVED OXYGEN PRODUCTION VS. DEMAND

Lemmon, S. D., August 10, 1955

Time	Duration of measurement, hours	Light intensity (F.C.) at -		Dissolved oxygen Relationships Lbs./Acre/Hr.			
		10 inches	38 inches	Total photosynthetic production	Total respiratory use	Surplus	Observed sewage influent B.O.D loading(ultimate)
9:00 AM	0.5	552	5.5	17.8	4.9	12.9	0.28
1:00 PM	1.0	780	7.8	12.9	5.9	7.0	0.28
3:00 PM	2.0	390	3.9	7.0	5.9	1.1	0.28
7:30 PM	2.0	55	<1.5	0.24	5.3	-5.1	0.28

the theoretical oxygen demand of the sewage can be grossly compared with that of the whole biological system. Such comparison suggests that the nutrients in sewage stimulate development of a biota with oxygen requirements considerably greater than that of the sewage itself.

Conditions in the light and dark bottles prevailing during a test differ from pond conditions in a number of ways. During daylight, especially on warm, calm days, temperature decreases with depth, commonly as much as 10.8°F. in 3-1/2 feet. Such gradients, which are generally formed before noon, disappear during high winds and after sunset so that temperature is fairly uniform with depth at such times. The algae, also, are not distributed uniformly with depth, but tend to concentrate toward the surface during dayti me and again become more uniformly distributed at night. This vertical fluctuation was also indicated by high daylight concentrations of chlorophyll in over-flow samples collected at three-hour intervals and low concentrations during darkness. Chlorophyll "A" concentrations at different depths in the Kadoka pond are shown in Table 11. A stronger vertical gradient is shown at noon than at other times of day. Similar vertical distribution of algae, as indicated by chlorophyll concentration, was noted at other locations also.

Table 11

VARIATION OF CHLOROPHYLL "A" CONCENTRATION
WITH SAMPLING DEPTH AND HOUR

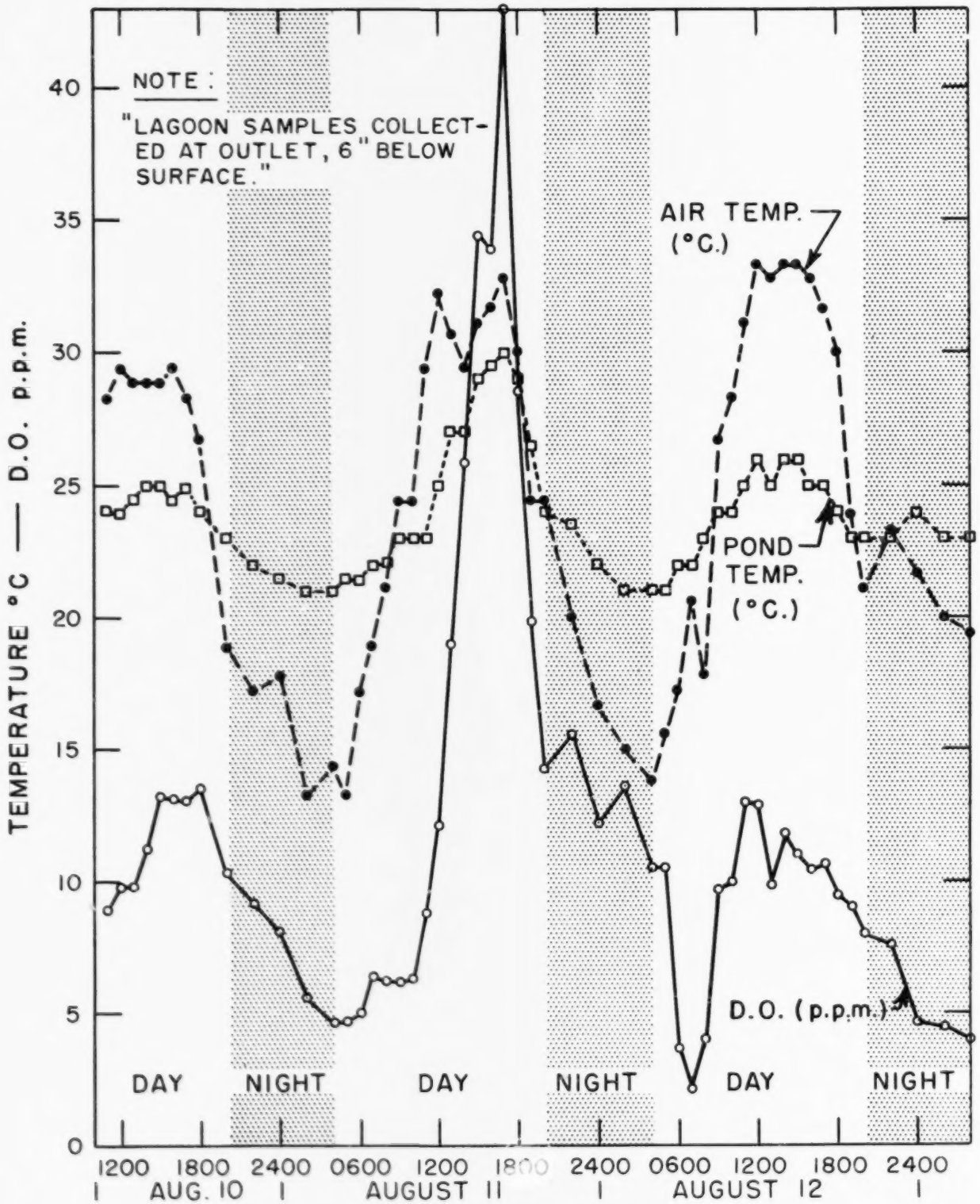
Kadoka, S. D., July 27, 1955

Depth, inches	10:45 AM	12:30 PM	5:45 PM
3	-	7.32 ppm	3.28 ppm
10	-	3.45	-
12	3.36 ppm	-	-
17	-	1.62	2.62
24	2.86	0.99	1.53
36	2.22	0.49	0.92
47	-	0.38	0.53

Because of these temperature and algal density variations with depth, bottle test data cannot be expected to simulate exactly the productivity in the pond itself. Further deviation may result from differential limitation of nutrients, especially CO_2, as the day progresses. It is likely that there are other related factors not now fully recognized. There is reason to believe that photosynthesis proceeds at a higher sustained level in the pond than in the test bottles.

In spite of these variations, the test data give better understanding than otherwise available, concerning the course and magnitude of diurnal fluctuations in dissolved oxygen. As shown in Figure 7, daytime peaks in dissolved oxygen concentration at 6 inch depth may range from near saturation to several times saturation because of the intense oxygen production by algae. Loss of oxygen to the atmosphere and respiratory use by the biota, the latter masked completely during the day by photosynthetic production, result in lowering the concentration to less than saturation at night. In certain ponds, generally, and in others only during a period of cloudy weather, nocturnal levels dropped to zero and remained there for from one to several hours. At such times, the period of oxygen depletion was sufficiently brief that objectionable odors did not develop.

At Lemmon, on August 10 and again on August 12, wind velocity was 13 to 18 miles per hour, whereas it was only 1 to 3 on August 11. It has been noted that wind of sufficient velocity to cause surface disturbance accelerates the rate of oxygen loss to the atmosphere. Apparently it is this phenomenon that explains the magnitude of the dissolved oxygen peaks observed on these three days. The diurnal pattern of dissolved oxygen change observed at 6 inch depth shows only part of the over-all pattern of change in the entire pond. At mid-



LEMMON, SOUTH DAKOTA

FIELD OBSERVATIONS, SUMMER 1955

48-B

FIGURE 7

day it is not unusual for D. O. concentration to be greater at 10 inches of depth than at 3 inches. Also, as shown in Figure 8, concentration at that time can shift from more than 30 ppm at 10 inches to zero just 26 inches deeper. This pattern also changes with time as oxygen invades and accumulates in the deeper layers after noon. At the time of these observations 99 per cent of the surface light was absorbed and presumably all appreciable photosynthesis occurred in the upper 16 inches of depth. Because of this the oxygen present below this depth, occasionally at concentrations exceeding saturation, must have come from above by diffusion and vertical mixing.

TEMPERATURE

Table 12 shows the difference between maximum and minimum temperatures recorded during spring and summer. The range of fluctuation decreased as the depth increased, which indicates a beneficial stabilizing effect on temperature of greater depths during the summer months. The relation of temperature to the diurnal fluctuation of dissolved oxygen is shown in Figure 7.

The main effect of temperature on the stabilization process is through its influence on the rate of the B. O. D. reaction, including algal respiration. A B. O. D. that could be satisfied in 4 days at 30°C. would require 13 days at 5°C.

Table 12

RANGE OF TEMPERATURE FLUCTUATIONS, ^{o}C

Season	Location and average depth in feet				
	Lemmon 5.7	Kadoka 4.4	Maddock 4.0	Wishek 3.0	Wall 1.2
Spring	3	7	5	16	18
Summer	9	7	11	11	17
Average Fluctuation	6	7	8	13.5	17.5

WIND DIRECTION AND VELOCITY

Table 13 has been included to show the wind conditions in the general areas of the Dakota investigation. Specific wind velocities and direction as measured at each pond are included in Appendix B.

Winds in the area of Rapid City, South Dakota, were from the NNW to NW during 11 out of 12 months; at least once each month the maximum velocity reached 42 m. p. h. In the area of Bismarck, North Dakota, winds were from the WNW to NW 8 out of 12 months and velocities were 39 m. p. h. or more at least once each month.

The water surface of stabilization ponds was observed to resist wave formation, apparently due to lowered surface tension, when winds

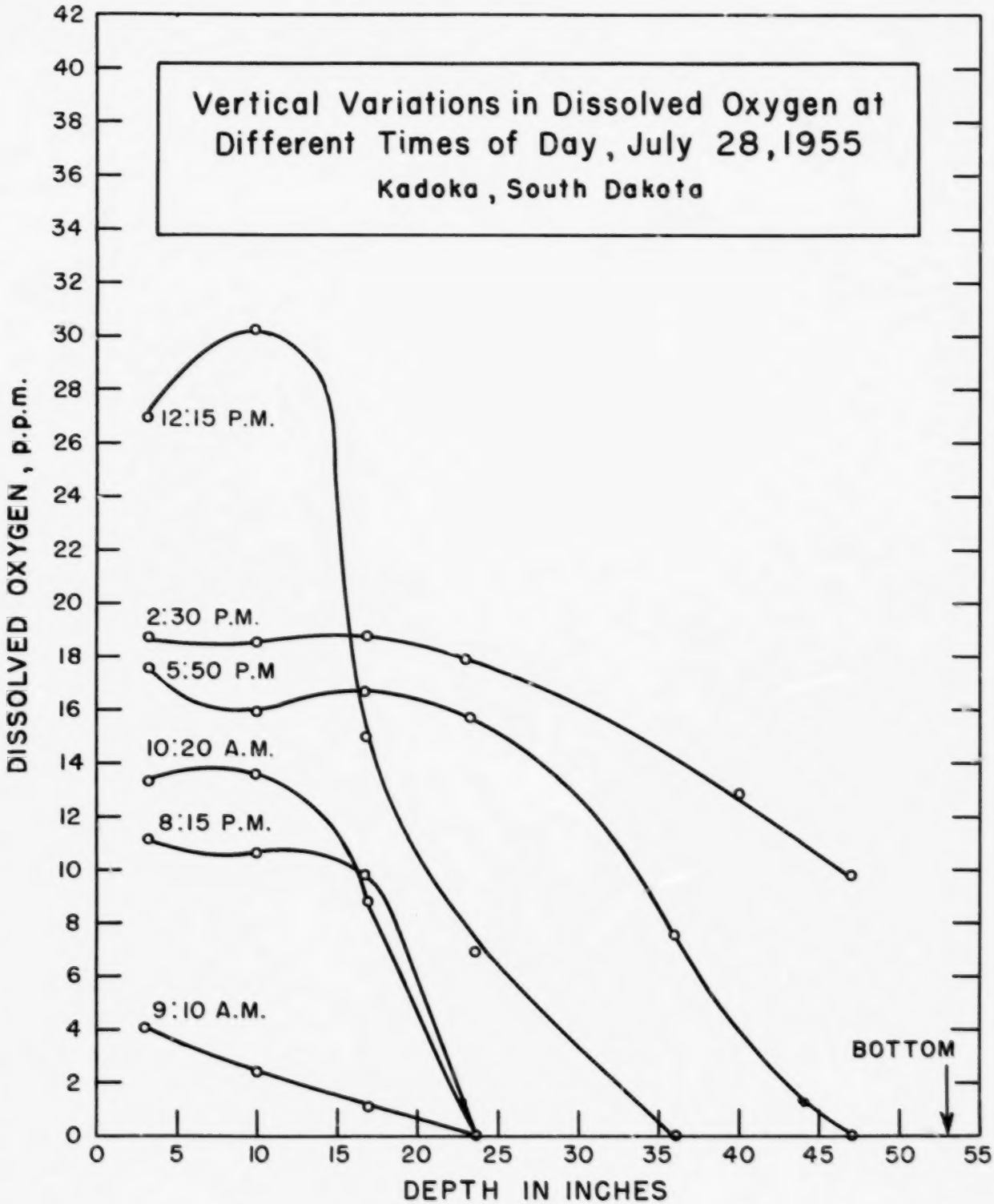

Vertical Variations in Dissolved Oxygen at Different Times of Day, July 28, 1955
Kadoka, South Dakota
DISSOLVED OXYGEN, p.p.m.
DEPTH IN INCHES
12:15 P.M.
2:30 P.M.
5:50 P.M
10:20 A.M.
8:15 P.M.
9:10 A.M.
BOTTOM
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
0
5
10
15
20
25
30
35
40
45
50
55

FIGURE 8

Table 13

PREVAILING WINDS, 1955

Month	Rapid City, S. D.			Bismarck, N. D.		
	Direc. tion	Ave. Vel. MPH	Max. Vel. * MPH	Direc. tion	Ave. Vel. MPH	Max. Vel. * MPH
Jan.	NW	10.8	42	NW	10.6	52
Feb.	NNW	12.2	54	NNW	12.4	47
March	NNW	13.2	56	WNW	13.0	54
April	NNW	13.7	45	WNW	14.8	63
May	NNW	13.3	50	SSE	15.2	56
June	NNW	12.1	56	WNW	11.4	39
July	SE	9.9	45	E	11.2	59
Aug.	NNW	9.2	43	E	10.7	56
Sept.	NNW	10.2	43	E	11.5	43
Oct.	NW	9.9	42	WNW	10.6	42
Nov.	NNW	11.4	50	WNW	14.5	45
Dec.	NNW	8.6	60	WNW	11.2	54

* Not always in direction of prevailing winds.

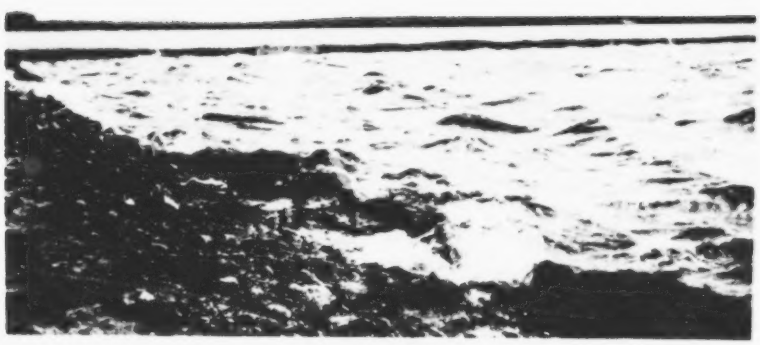
are less than 30 m. p. h. However, wind velocities exceeding 35 m. p. h. sometimes caused waves over a foot high. Figure 9. The turbulence produced by these waves and subsequent counter currents contribute to complete dispersal of settleable solids during open water seasons. Surface agitation by high winds was observed to lower the degree of D. O. supersaturation in the top layer of the ponds. Although much of this oxygen is lost to the atmosphere, some of it is undoubtedly mixed into the deeper layers not readily reached by diffusion.

The apparent beneficial effects of wind should be utilized by locating the pond for maximum exposure to prevailing winds. The distance for which obstacles such as trees, hills, and other objects will markedly reduce wind effect is 20 times (Ref. 1952-(3)) the height of the obstruction, with some diminution for twice that distance. There is considerable reduction even by the shelter of low shores on the windward side. See Figure 10.

EVAPORATION, PRECIPITATION, AND SEEPAGE

The state of the hydraulic balance [(applied sewage flow + precipitation)-(evaporation + seepage) = effluent] will determine the annual amount of effluent discharged, if any.

FIGURE 9



WAVES CAUSED BY WINDS OVER 30 M.P.H.
MADDOCK, NORTH DAKOTA

5-9-55

VIEW OF DIKE SEPARATING NO. 1 AND NO. 2 PONDS.
FACING SW, NO. 1 POND IN FOREGROUND

FIGURE 10

EFFECT OF TOPOGRAPHY ON WAVE FORMATION
KADOKA, SOUTH DAKOTA

4-23-55

NOTE QUIESCENT SURFACE AT A & B
WHERE WIND IS OBSTRUCTED BY HILLS.

If no effluent is to be discharged, then the above equation must equal an average of zero over an extended period of time. A fluctuation in water level may be expected with each of the variables, but a consistently negative value could result in lowering the pond to an inoperative level. Table 14 represents an estimated balance of the flow in each of the five ponds studied.

Table 14

ANNUAL (1955) HYDRAULIC BALANCE
EXPRESSED IN INCHES OF WATER LEVEL

	Kadoka	Lemmon	Wall	Maddock	Wishek
Applied sewage	94.7	62.3	37.6	21.1	98.8
Ppt'n	16.3	32.6	13.9	17.1	18.3
Total inflow	111.0	94.9	51.5	38.2	117.1
Evaporation	38.9	58.8	38.9	32.9	43.2
Effluent	63.7	9.1	0	0	?
Total out, less seepage	102.6	67.9	38.9	32.9	43.2
Seepage*	8.4	27.0	12.6	5.3	73.9**

* Approximate. In non-overflow ponds, seepage may be less than indicated, the difference being accounted for by a rise in water level.

** Includes seepage, releases by a drain valve operated at the discretion of the water and sewage attendant, and change in water level.

SOIL CHARACTERISTICS

Limited soil studies were made during the summer of 1955. Observations made at the five installations subjected to seasonal study are shown in Table 15.

The sodium content of water was of interest because excess of sodium makes soil less permeable, and may tend to help seal the pond bottom. The Bureau of Reclamation, U. S. Department of the Interior, states: "If the (irrigation) water contains more sodium than it does calcium and magnesium, there is a tendency for this sodium to replace the calcium and magnesium already in the soil. Since the presence of an excess of sodium makes soil less permeable, the effect of irrigation with water containing an excess of sodium is to tighten or seal up the soil. This effect may not be evident for a long time if the total salt content of the irrigation water is low. It is generally believed that the ratio of sodium ion to the sum of sodium, magnesium, and calcium ions in irrigation water should not exceed 50 or 60 per cent." (Irrigation Adviser's Guide, U. S. Dept. of Interior, Bur. of Reclamation, p. 18, (1951))

Seepage is a variable that can prevent an optimum operating level from being attained. Soil analysis alone is not sufficient to predict ultimate liquid loss by seepage. Sodium content of the overlying

Table 15

SOIL-RELATED OBSERVATIONS

Observation	Kadoka	Wall	Lemmon	Maddock	Wishek
Soil Analysis*					
Sand, %	25.7	6.3	34.5	22.8	16.1
Silt, %	41.5	68.7	38.5	56.3	59.6
Clay, %	32.8	25.0	27.0	20.9	24.3
Municipal Water					
Sodium, %	88.3	92.3	59.7	68.2	45.9
Dikes					
Steepest slope	1:1	1:2	1:1.5	1:3	1:4
Top width (ave.)	14'	11'	10'	3'-17'	14'
Erosion	None	None	Severe on SE corner	E Bank #1 Pond	Rip-rapped

* Mechanical soil analysis performed by Soils Lab., Bur. Rec., Bismarck, N. D.

liquid may have an appreciable effect on sealing the bottom by altering its chemical content. Further study is needed to correlate soil characteristics with seepage. Meanwhile, the following statements regarding the subject should be considered fundamental:

(1) No seepage should be permitted access to wells or ground water supplies. Initial location of the pond must take cognizance of this.

(2) Gravel and limestone must be avoided unless covered with an adequate layer of tightly packed clay. A seepage rate of 3/16" per day over one acre would remove over 5000 gallons of water - the equivalent of treatment capacity for 100 persons at 50 gallons per person per day. Sodium content and sewage solids per se should not be relied upon for sealing a permeable pond bottom. See Chapter V (page 66) for correlation of seepage, evaporation, and precipitation to total daily water loss.

MUNICIPAL WATER SUPPLY

The possible sealing effect of a high sodium content in the water applied to the stabilization pond has been noted. Highly mineralized waters common in the Dakotas may influence the nature of biological activity in the ponds also. Table 16 lists pertinent analyses of municipal water supplies at the five installations studied. The high sulfate content of the Kadoka water may have contributed to the sulfide production there during all seasons. However, relatively heavy B O. D. loading, irregular shape and depth, and a peninsula inlet may all have been contributing factors.

ICE COVER AND ICE MELT

Photosynthetic activity by algae diminishes with drop in temperature and formation of ice, especially when the ice forms quickly

Table 16

MUNICIPAL WATER SUPPLIES

Detail	Kadoka	Wall	Lemmon	Maddock	Wishek
Source	Well	Surface	Wells	Wells	Well
Pop. Served	580	560	2760	740	1200
Consumption GPD	20,000	26,000+	100,000 (est.)	43,000 (Av. '54)	60,000
G/cap/day (gcd)	32+	46+	180	58	71
Treatment	Chlorination	Coag-Filt Chlorination	None	None	None
ANALYSIS*					
Total dissolved solids	1841	207	1498	915	260
Total alkalinity	150	154	---	336	340
Total hardness (as $CaCO_3$)	222	75.5	180	260	3.1
Iron (Fe)	0.0	0.0	0.5	1.4	8.0
pH	7.6	8.0	8.3	7.6	101
Calcium (Ca)	66.5	24.0	8.4	61.6	21
Magnesium (Mg)	13.5	2.8	2.5	26.0	---
Sodium (Na)	511	55.5	560**	158	---
Fluoride (F)	1.4	0.6	2.8	Trace	---
Chloride (Cl)	72.0	11.0	91	10	14
Sulfate (SO_4)	1038	17.4	362	244	52
Bicarbonate	183	193	903	410	317
Nitrate (NO_3)	2.0	0.0	0.2	2.1	---
Carbonate	---	---	---	---	---
Manganese (Mn)	0.0	0.0	---	---	---

* Expressed in parts per million.

** Includes potassium.

during high winds and becomes somewhat opaque. An example of this condition is shown in Figure 11.

The stabilization ponds studied did not appear different from any fresh water lake or pond during winter conditions. Where the inlets were submerged and located at or near the center a small area of open water could usually be seen above it. However, no odors could be detected despite the anaerobic condition that prevailed under the ice.

Thickness of the ice was also comparable to that on bodies of fresh water in the area. Maximum ice thickness of 41-1/2 inches was observed at the Newtown, N. D., installation on March 14, 1956. Treatment obtained under ice was discussed in Chapter III. Actual concentrations of B. O. D., total alkalinity, chloride, ammonia and total phosphorus as phosphate under ice and in open water are shown in Tables 17 and 18, respectively.

The effects of ice cover on stabilization pond operation include the following:

1. Photosynthesis is negligible.
2. Liquid becomes anaerobic.
3. Low temperatures inhibit biological activity. Anaerobic decomposition occurs, but at a slow rate.

FIGURE 11

AFTERNOON

11-1-55

MORNING

11-2-55

(NOTE OPAQUE CONDITION OF ICE,
ABOUT 2 INCHES THICK)

EXAMPLE OF RAPID ICE FORMATION
MADDOCK, NORTH DAKOTA

58-B

Table 17

UNDER ICE CONDITIONS

Laboratory Analyses - Winter 1955

Analysis	Kadoka	Wall	Lemmon	Maddock	Wishek
B. O. D., ppm	43	168	31	83	150
Total alkalinity, ppm	791	1200	853	900	771
Chloride, ppm	218	335	203	285	125
Ammonia, ppm	25	60	8	20	60
Suspended solids, ppm	74	92	63	49	84
Total phosphorus as phosphate, ppm	48	73	17	26	57
Total depth, feet	4.4	1.17	5.7	4.0	3.0
Ice thickness, feet	0.9	0.92	1.2	2.0	1.9
Fluid beneath ice, feet	3.5	0.25	4.5	2.0	1.1

Table 18

OPEN WATER CONDITIONS

Laboratory Analyses - Spring, Summer and Fall 1955

Analysis	Kadoka	Wall	Lemmon	Maddock	Wishek
B. O. D., ppm	36	41	19	10	32
Total alkalinity, ppm	768	528	738	621	336
Chloride, ppm	165	156	203	184	61
Ammonia, ppm	10	3	2	9	17
Suspended solids, ppm	111	556	91	89	156
Total phosphorus as phosphate, ppm	42	32	13	13	17

4. Liquid beneath ice circulates by convection currents induced by warm sewage. Velocity of these currents is not great enough to move settleable solids, so an accumulation of sludge develops around inlet.

5. Concentration of dissolved organic and inorganic material increases in the remaining liquid as ice increases in thickness. This is especially notable in non-overflowing ponds.

A typical winter-spring transition consists of three distinct steps: (1) the ice melts, (2) the sludge island around the inlet is disintegrated and dispersed throughout the pond, and (3) a dense algal population is re-established.

The following observations were made at the Kadoka pond during the period of ice-melt from March 26 to April 5, 1955. Open water first appeared around the periphery of the pond and in a circle of increasing diameter over the inlet. With the decrease in volume in the change from ice to water, the pond level dropped slightly and revealed the top of an island of sludge around the inlet. High velocity winds soon disrupted the surface pattern while pieces of the disintegrating ice were broken off and carried to the downwind shore, where warmer littoral water accelerated melting. This breaking-off

process continued until chunks of ice were blown in line with the sludge island and the top layer of solids removed. Dispersal of the remaining solids was accomplished as a result of wave induced turbulence.

The critical stage of the winter-spring transition was noted when the ice seal had been removed and the rate of bacterial decomposition increased with the rising temperature of the pond contents. Surface aeration was not sufficient to satisfy the demand for oxygen, and the pond remained septic until a dense population of algae became established. Algae then accumulated at the surface and were distributed by wind action as shown by a concentration first observed in downwind sections. Dense populations of algae next were observed around the entire periphery, interrupted by gray striations. Finally a uniform green color developed throughout the pond coincident with measurable concentrations of dissolved oxygen. Table 19 lists observations of the six North Dakota stabilization ponds during the winter-spring transition of 1956.

From the information in Table 19 the salient causes of delayed spring recovery appear to be lack of wind action, excessive depth, and loadings greater than 100 persons per acre. Detailed field observations made during the winter-spring transition are recorded in Appendix D.

Table 19

WINTER-SPRING TRANSITION OF SIX PONDS, 1956

Community served	Recovery time, days*	Estimated loading, persons/acre	Depth feet	Remarks
Newtown	53	163	4	Protected from NW wind
Watford City (#1)	50	134	8	Filled to top of dike
Beach (#1)	38	190	4	WL lowered from 8' to 4' prior to ice melt.
Elgin (#1)	27	83	4	WL lowered from 8' to 4' prior to ice melt.
Dunn Center	Less than one week**	36	3	
Center	Less than one week**	45	5	

* Number of days between time of complete ice melt and first detection of D. O.

** As observed by municipal personnel.

STARTING NEW FACILITIES

Assuming a flow of 50 gallons per capita, 100 persons could furnish 5000 gallons daily. Over an area of one acre, 69 days would be required for this flow to raise the water level one foot. This calculation disregards seepage, evaporation, and precipitation, and since evaporation exceeds precipitation throughout the Dakotas, the rate increase in depth would be somewhat less than the theoretical. The expected time lag in attaining an optimum water level is pertinent to selecting the season for initiating operation.

Despite the characteristically low temperature of the Dakota winters, there was little evidence of inlet clogging due to freezing. When starting pond operation during the winter, only one inlet was observed to have frozen. This was at the installation serving the south section of Watford City. Because there were very few house connections to the inlet at the time of freeze-up, the abnormally low flow did not have sufficient heat to keep the inlet clear. Ponds at Hope, New Salem, Scranton, New England, and Plaza, North Dakota, and Clear Lake, Freeman and Isabel, South Dakota, operated with exposed inlets through the winter of 1955-56 without any report of clogging due to freezing.

Observations were made of initial operation during the spring, summer and fall seasons in South Dakota. Algal growths developed almost at the outset of application of raw sewage.

The most favorable time to start a pond is in the spring or early summer; however, no seriously undesirable conditions have been reported on any adequately designed pond, regardless of when operation started. Auxiliary dilution water has not been found necessary in ponds other than those with complete retention.

Chapter V

STRUCTURAL FEATURES AND DESIGN CONSIDERATIONS

AREA

Three basic types of operation must be considered in incorporating area into the design: (1) total retention (no overflow), (2) intermittent drawdown (based on receiving stream requirements), and (3) continuous overflow.

Fundamental to each type is the maximum loading of the flow and strength equivalent of 100 persons per acre. This is primarily a unit of convenience to be used where actual per capita B. O. D. and flow are unknown. Where they are known, a more specific maximum limit of 20 lbs. B. O. D. per acre per day should be used. Minimum allowable flows per unit of area will depend on the local soil conditions, evaporation, and precipitation. Figure 12 may be used as a guide in determining minimum flows per acre.

For complete retention, the flow of applied sewage per acre must balance the natural water loss. A fluctuation in water level should be expected with seasonal variation in water consumption, evaporation and precipitation. The following example is offered for comparison with the existing installation at Maddock.

(1) Seepage = 1/64" per day (assumed in this example but should be measured on site).

(2) Evap. - Ppt. = 16" per year (From climatological records).

(3) From Figure 12, average daily flow must be 1600 GPD per acre.

(4) Measured flow during 1955 investigation, 50,200 GPD.

(5) Area required, $\frac{50,200}{1,600}$ = 31.4 acres. Actual area of present installation is 32 acres.

Similar calculations may be made for ponds designed for intermittent drawdown, continuous discharge, or multiple cell installations.

DEPTH

Optimum depth varies with the season of the year. During winter months, when ice thickness may vary from less than one foot to well over three feet, a total depth of five feet is desirable. In the early spring, immediately after the ice has melted and high winds have dispersed the settled solids, a shallow depth of about 2.5 feet would encourage resumption of rapid algal growth. In late spring, summer, and early fall an intermediate depth of three to four feet should produce more uniform temperature conditions. As shown in Figure 8 dissolved oxygen can occur at the bottom of a pond this deep at least during a part of the day.

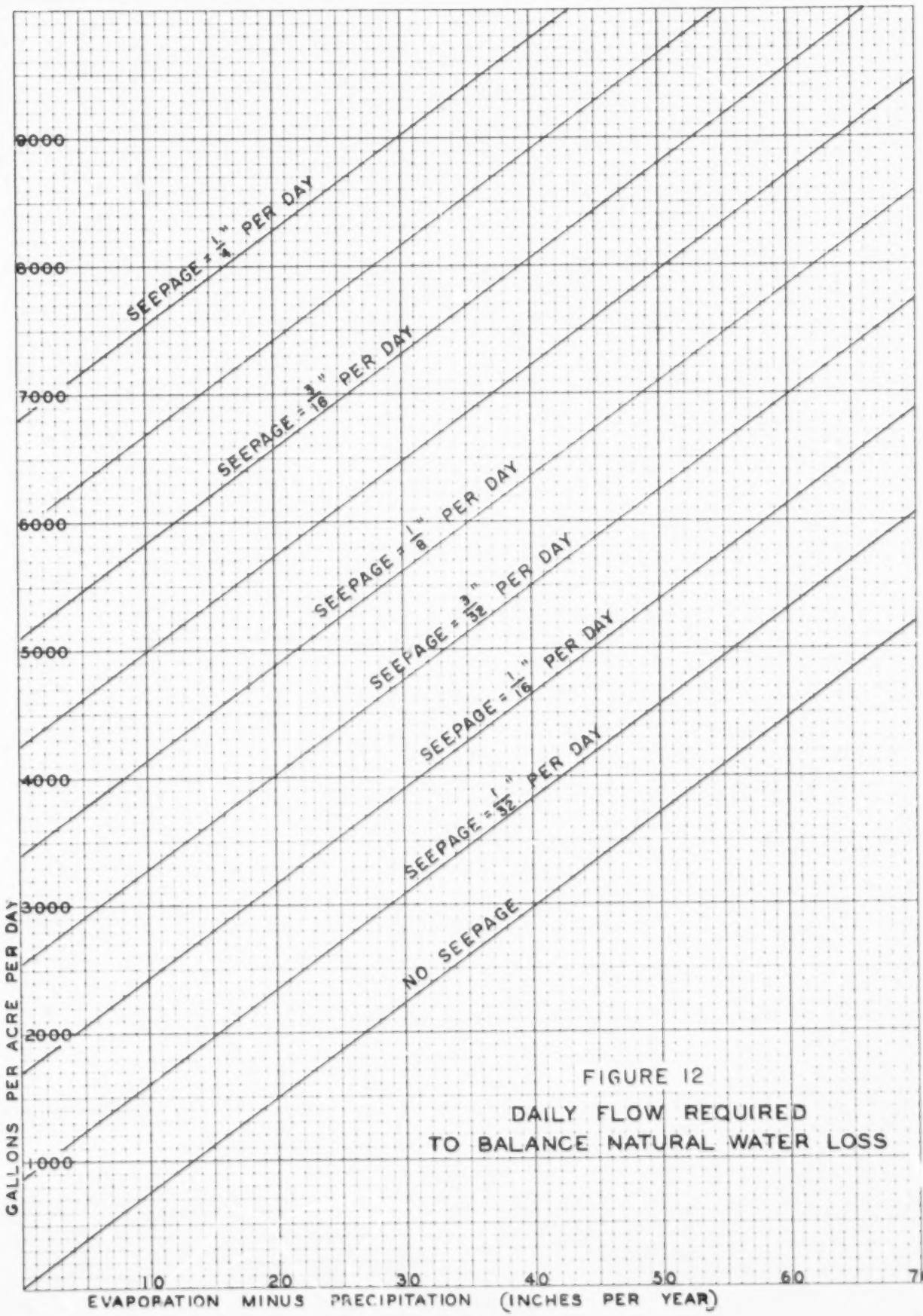


FIGURE 12

DAILY FLOW REQUIRED
TO BALANCE NATURAL WATER LOSS

66-B

SHAPE

Over-all shape of a sewage stabilization pond is not particularly relevant except as it relates to the surrounding topography Where existing natural contours are used, the remaining hills may act as a wind shield. Whether round, square or polygon-shaped, the perimeter must be uniform; coves, islands or peninsulas should be prohibited, as they interfere with circulation and may develop local nuisance conditions.

DIKES

Dikes or embankments should be constructed to facilitate maintenance of a clean, weed free shore line with slopes as given in the Suggested Design Criteria. Erosion protection such as rip-rap should be incorporated at the time of initial construction at least along the banks subjected to wave action from the prevailing winds. The dikes should be constructed so as to be impermeable by the most feasible local method. Top width should be at least eight feet to permit access of maintenance vehicles. Freeboard will depend on local frost disturbance, but should not be less than three feet above maximum operating level; however, excessive height may prevent access of wind to pond surface.

INLET STRUCTURE

1. Location

Side inlets discharging less than fifty feet from the shore should be avoided. Such inlets were observed at Kadoka, Wall, Wishek, Max and Flaxton, and all had local nuisance conditions around the inlet. A center, or near-center location for the inlet allows equal dilution on all sides and permits maximum circulation and mixing by wind-induced currents. It is, therefore, ideal for complete retention installations or installations designed for occasional drawdown. Flow-through installations, with a continuous discharge, may well use an inlet located toward the leeward shore with respect to prevailing winds, but not nearer than 100 feet. This should permit maximum dispersal of settled solids.

In multiple cell installations operated in series the above remarks concerning inlets apply only to the first cell. Inlets to subsequent cells may discharge near the dike. Possible damage from heavy ice makes it mandatory that inlets be located not more than one foot off the bottom.

2. Type

Gravity-flow inlets should have a horizontal bottom discharge, since any change in direction of the low velocity flow under

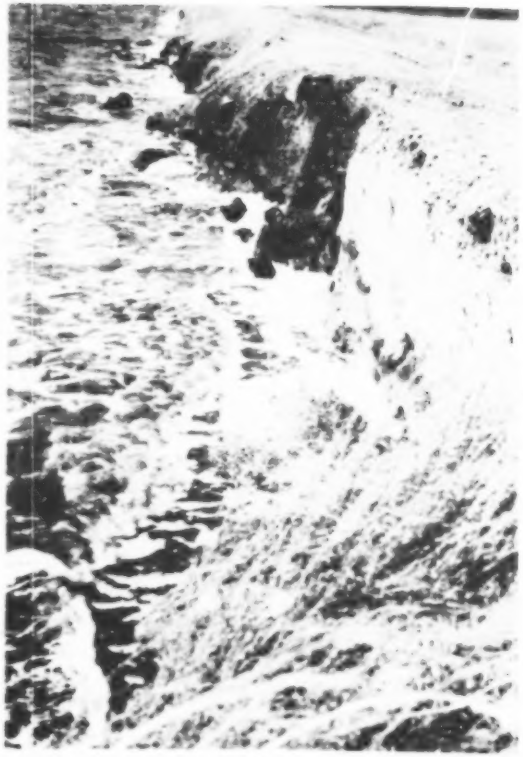


FIGURE 13

DIKE EROSION
LEMMON, SOUTH DAKOTA
5-3-55

EROSION AT
SOUTHEAST CORNER
LOOKING NORTH

the pond surface may cause clogging. Force-main inlets may use the available pressure at the point of discharge to get maximum dispersal by utilizing an upward slanting flow. However, a horizontal, bottom discharge was utilized at Maddock, and is apparently quite satisfactory.

OVERFLOW STRUCTURE

1. Location

Location of the outlet near the windward shore should prevent any wind-induced short circuiting and permit maximum time-distance between inlet and outlet.

2. Type

Maximum flexibility in stabilization pond operation may be facilitated by incorporating pond level and effluent draw off level controls in the overflow. An example of such controls is a stop-plank support in a manhole for pond-level control and an adjustable level intake structure to the manhole. Figure 14 shows an existing stop-plank support enclosed in an overflow manhole.

SIZE

Size is determined by the loading of 100 persons or 20 pounds of B. O. D. per acre, as given in the Suggested Design Criteria.

MULTIPLE PONDS

In considering the use of one large pond versus multiple smaller ponds, the following observations are pertinent:

1. A single, non-overflowing pond will permit no control of the water level; the level will drop during dry seasons, and rise during the rainy seasons. Auxiliary water will be required to attain an initial operating level.

2. A single, continuously overflowing pond, equipped with a level-control outlet may be used where the receiving stream can assimilate an algal-laden effluent.

3. Water in successive ponds of a multiple-pond installation operated in series will not be available for diluting the contents of the first pond unless artificial recirculation is practiced. See Figure 15.

4. Parallel operation offers flexibility in handling fluctuating loads such as are experienced in communities that have a large seasonal influx of tourists. However, each pond of a parallel multiple pond arrangement must have its own center, or near-center inlet.

5. From the observations made during the Dakota study, a two pond arrangement would appear to have merit for reasons previously stated. Size and cost may be limiting factors.

FIGURE 14

STOP-PLANK SUPPORT IN OVERFLOW MANHOLE
NEWTOWN, NORTH DAKOTA

VIEW INSIDE OF OVERFLOW MANHOLE

FIGURE 15

CONTRAST IN SURFACE CONDITION
OF MULTIPLE PONDS IN SERIES
MADDOCK, NORTH DAKOTA
5-20-56

POND AT RIGHT RECEIVES RAW SEWAGE AND
LEFT POND IS THIRD IN SERIES

BOTTOM

The pond bottom must be level for uniformity of water level control and maximum utilization of wind-induced currents for mixing. No obstruction to circulation such as raised inlet pipes, debris, or weed growth should be present when the initial application of sewage is made.

LOCATION

Locating the site of a proposed sewage stabilization pond must be based on several factors. Conflicts between some of these factors is almost inevitable and can only be resolved by the local and State authorities.

1. Cost of land.
2. Elevation.

   Gravity flow versus expensive pumping.
3. Prevailing winds, especially those of early spring.

Wind direction is significant in the selection of a site for construction and in locating the inlet and outlet structures. Odors may be produced during the winter-spring transition; for this reason the pond should be located downwind from the community served. Since the prevailing winds are generally from the NW in the Dakotas, the optimum location would be SE from the community.

4. Topography.

Hills and trees may obstruct wind.

5. Soil characteristics.

Gravel and limestone must be avoided. Seepage rate of over 3/16 inch per day may require artificial sealing of bottom.

6. Proximity and direction of flow in ground water aquifers.

FENCING AND SIGNS

The installation of fencing and "no trespassing" signs is mandatory. Although there are even less hazards associated with a stabilization pond than with a conventional treatment plant, the former is unattended most of the time. The purpose of the signs is to notify persons of the nature of the facility which has been found necessary because existing installations have already been mistaken for fresh-water reservoirs and consequently used for boating (Maddock, N. D.), vehicle washing (Rollo, N. D.), road construction water supply (Wall, S. D.), and even swimming, the last by children of itinerant farm workers at Lemmon, S. D.

Minimum requirement for fencing is that it be stock tight, not only to prevent cattle from drinking from the pond, but to prevent them from trampling the inner side of the dike.

PRETREATMENT

Under conditions in the Dakotas, where strong winds are available for the dispersal of settleable solids, treatment of the sewage prior to application to the stabilization pond is normally superfluous. Although some savings in land costs may be realized by lessening the loading to the pond, the initial cost of a primary treatment plant plus continual operating and maintenance costs usually negate the saving.

Chapter VI

PUBLIC HEALTH CONSIDERATIONS

HUMAN CONTACT

A sewage stabilization pond should be operated with the same precautions as are practiced in a conventional sewage treatment plant. A large open body of water is especially attractive to children, and incidents of boating, ice-skating, and even swimming in stabilization ponds have been reported. Although the efficiency of bacterial removal as measured by the MPN of coliform is very high, the possibility of infection by contact with sewage while in the process of being stabilized must be recognized. Hence, the need for fencing and signs prohibiting trespassing.

Effluent from a properly designed stabilization pond is comparable to that from conventional secondary treatment plants. It may, therefore, be used for irrigation in accordance with State Health Department regulations regarding such use of secondary treatment plant effluents.

Ground water aquifers, especially those used for municipal or domestic water supplies, should not be accessible to stabilization pond seepage. Although the probability and extent of bacterial

and chemical contamination through various soils was not established in this investigation, sound public health practice forbids direct contact of sewage plant effluent with a domestic ground water supply.

Aerobic stabilization ponds are frequented by wildfowl just as are fresh water lakes, ponds, or sloughs in the Dakotas. The relative area of water surface of the stabilization ponds is insignificant in comparison with the many natural bodies of open water, and the per cent of total wildfowl contacting the former may be considered similarly small. No cases of infection among waterfowl hunters have been reported although hunters are known to utilize these ponds. Nevertheless, hunting or any other recreational use of the pond and its immediate area should be prohibited as a precautionary public health measure.

LIVESTOCK

The practice of watering livestock with stabilization pond contents or effluent should be discouraged until the possibility of infection by bacteria or parasites, or poisoning by toxic algae, has been investigated.

MOSQUITOES

A mosquito survey of 26 Dakota stabilization ponds was conducted July 30 - August 8, 1956. A report of this study indicates that:

1. Waste stabilization ponds may produce mosquitoes of several kinds,
   a. when they are being filled but have not reached operating depth and therefore contain terrestrial and emergent or submerged aquatic plants,
   b. when terrestrial plants along the shore extend into or hang into the water, and
   c. when submerged and/or emergent aquatic plants grow along the shore or elsewhere in the pond.

2. Production will be negative or of little consequence if weed growth is prevented or eliminated.

3. Larviciding be done as necessary on facilities as needed, especially if there is difficulty during the filling period.

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